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Bolt Beranek and Newman, Inc, Cambridge, Mass

Prepared for

Environmental Protection Agency, Arlington, Va Office of Noise Abatement and Control

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A series of aircraft noise regulations has been proposed by EPA to FAA for consideration under the procedures of the Noise Control Act. One of the components involved in these regulations is an assessment of their effect on reducing noise impact, i.e., the effect on public health and welfare if the regulations are implemented. This report utilized the concept of fractional impact analysis to assess several of the proposed regulations. In this concept the number of decibels that a noise exposure exceeds the identified levels specified in the EPA levels report determines a fractional impact index.

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ANALYSIS OF THE PUBLIC HEALTH AND WELFARE EFFECTS OF EPA PROPOSED AIRCRAFT NOISE REGULATIONS

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ANALYSIS OF THE PUBLIC HEALTH AND WELFARE EFFECTS OF EPA PROPOSED AIRCRAFT NOISE REGULATIONS

1. INTRODUCTION

A series of aircraft noise regulations has been proposed by EPA to FAA for consideration under the procedures of the Noise Control Act[1-6]. One of the components involved in these regulations is an assessment of their effect on reducing noise impact, i.e., the effect on public health and welfare if the regulations are implemented.

This report utilizes the concept of Fractional Impact Analysis to assess several of the proposed regulations. In this concept the number of decibels that a noise exposure exceeds the "identified levels" specified in the EPA "Levels" report[7] determines a fractional impact index. Partial impacts are found by multiplying the appropriate fractional impact index by the number of people exposed to each level of noise exceeding the "identified level." The total impact is then obtained by summing the individual partial impacts to obtain a single number that represents the total effect of an environmental noise on the population. (See Appendix 1.)

An analysis of the effect of a regulatory action using the fractional impact method has three basic parts. First, a model is required to relate noise exposure at various levels to the affected population. Use of this model, with a knowledge of existing noise levels and operational factors, defines a current status of noise impact, which provides the baseline against which future actions can be assessed.

The second step is to develop a model for projecting the effect of a regulation on noise exposure. This model must take into consideration the time effects of the regulation as well as the continued presence of noise sources not subject to regulation. The third step in the process is to couple the two models to obtain the change in total impact, as a function of time, resulting from the implementation of the regulation. It is usually convenient to describe the change as a percentage of the baseline case.

The development of noise models for impact analyses should, whenever possible, consider the fraction of the total national population that is affected by the noise. In some instances data are not readily available to formulate appropriate models. In these cases a parametric model formulation can be used to bracket several possible noise environments that would encompass any situation likely to occur in the nation. In the following analyses both national and parametric models are employed.

The proposed regulatory actions are grouped as follows:

1. Flight procedural requirements and equipment retrofit of current subsonic turbojet (and turbofan) transport category aircraft;

2. Noise certification requirements for propeller driven small airplanes;

3. Introduction of a limited number of supersonic transport operations to selected airports.

The effect of these proposals on public health and welfare, as expressed in terms of change in cumulative noise impacted population, are considered separately in the remainder of this report.

2. ANALYSIS OF THE IMPACT OF REGULATIONS AFFECTING SUBSONIC TURBOJET AIRCRAFT

Four regulations that are under consideration to reduce the noise from existing subsonic turbojet aircraft are considered here:

1) Minimum vectoring altitude of 3,000 feet above terrain on approach[2]

2) Use of a 6°/3° two-segment glide slope on approach[5]

3) Takeoff procedures employing climbout at reduced thrust[6]

4) Retrofit of current aircraft to conform with the noise requirements of FAR Part 36. (SAM)[3]

The development of models to assess the impact of these proposals is described in this section.

The primary source of data for these analyses is the DOT "23 Airport Study,"[8] supplemented by studies for the Aviation Advisory Commission[9,10]. These studies use 1972 as the baseline year, and report noise exposure in units of Noise Exposure Forecast (NEF). In this analysis we retain 1972 as the baseline for "as is" conditions, and translate to Day/Night Average Sound Level (L_{dn}) by adding 35 decibels to NEF in determining fractional impacts. The referenced studies do not extend to noise exposures below 30 NEF, thus we are constrained to an analysis of noise exposures equivalent to

65 L_{dn} and above. Since we are interested in the percentage change in impact introduced by the regulations, we believe the range of noise exposures considered is adequate for this purpose.

A number of estimates have been made previously on the number of people in the United States exposed to various levels of aircraft noise, including the estimate provided in the EPA "Levels" document, assuming that most noise impact arises from air carrier airports. The completion of the 23 Airport Study allows a more refined model to be developed since, for the first time, an actual population count based on the 1970 census data is available for noise exposures of 30 NEF or higher at these airports. (All previous estimates have been obtained by multiplying noise exposed areas by an average urban population density of 5,000 residents per square mile.)

Data are provided in Ref. 8 on the total population, total area, and the impacted area (total area minus airport and water areas) for each of the 23 airports. Figures 1, 2, and 3 show the populations exposed to NEF 30, 40, and 45, for 1972 operations, as a function of the number of daily operations. These data can be used to derive empirical functions relating numbers of operations to populations exposed at various NEF values. The functions are derived on the basis of linear or exponential least-squares regression analyses.

Since there is a substantial variation in the geographical relationships between airports and their surrounding communities, we have segregated airports into "high" and "low" impact configurations, largely related to the location of the airport relative to the population center and the surrounding area.

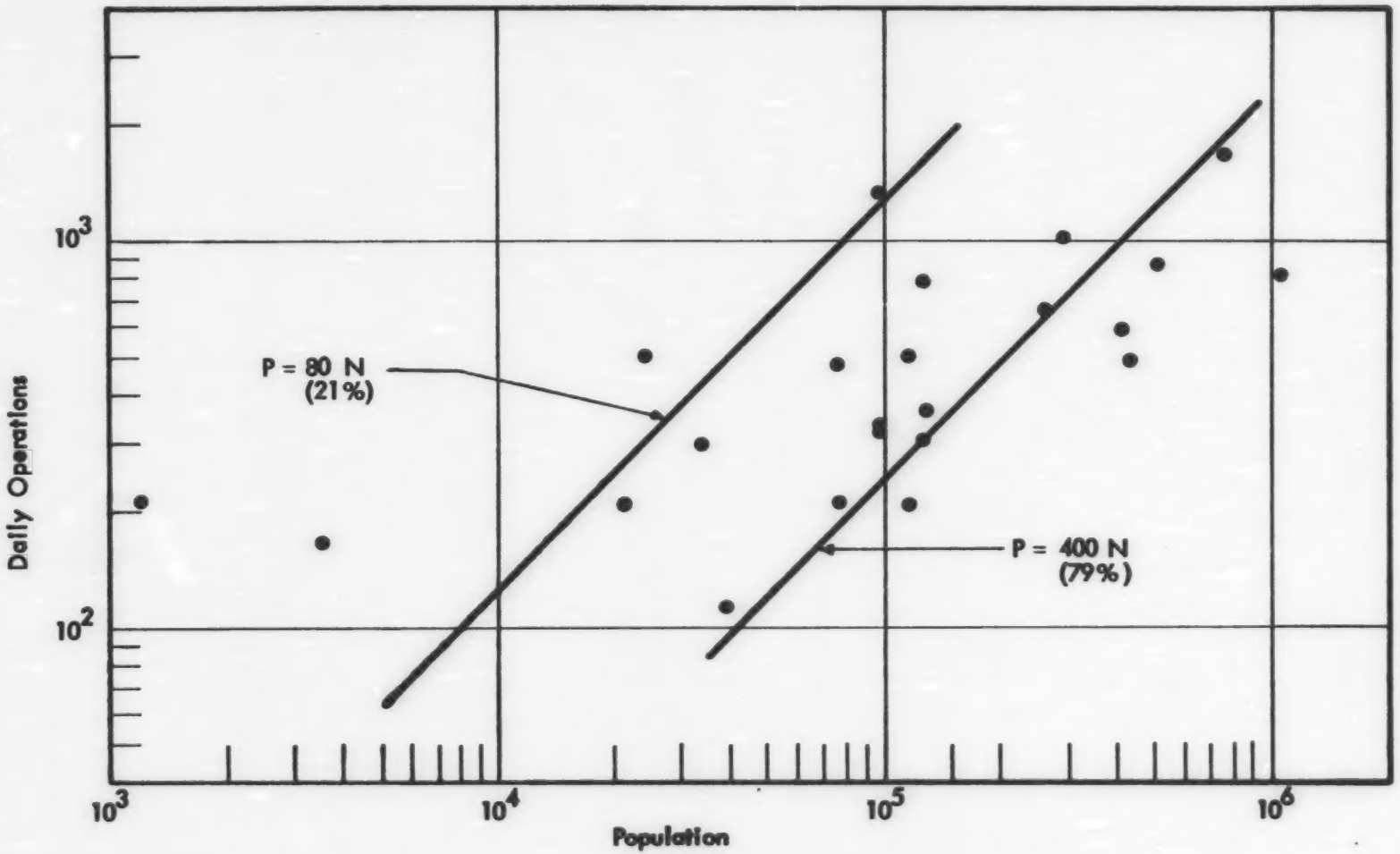

FIGURE 1. 23 AIRPORTS - 1972 BASELINE POPULATION WITHIN NEF 30

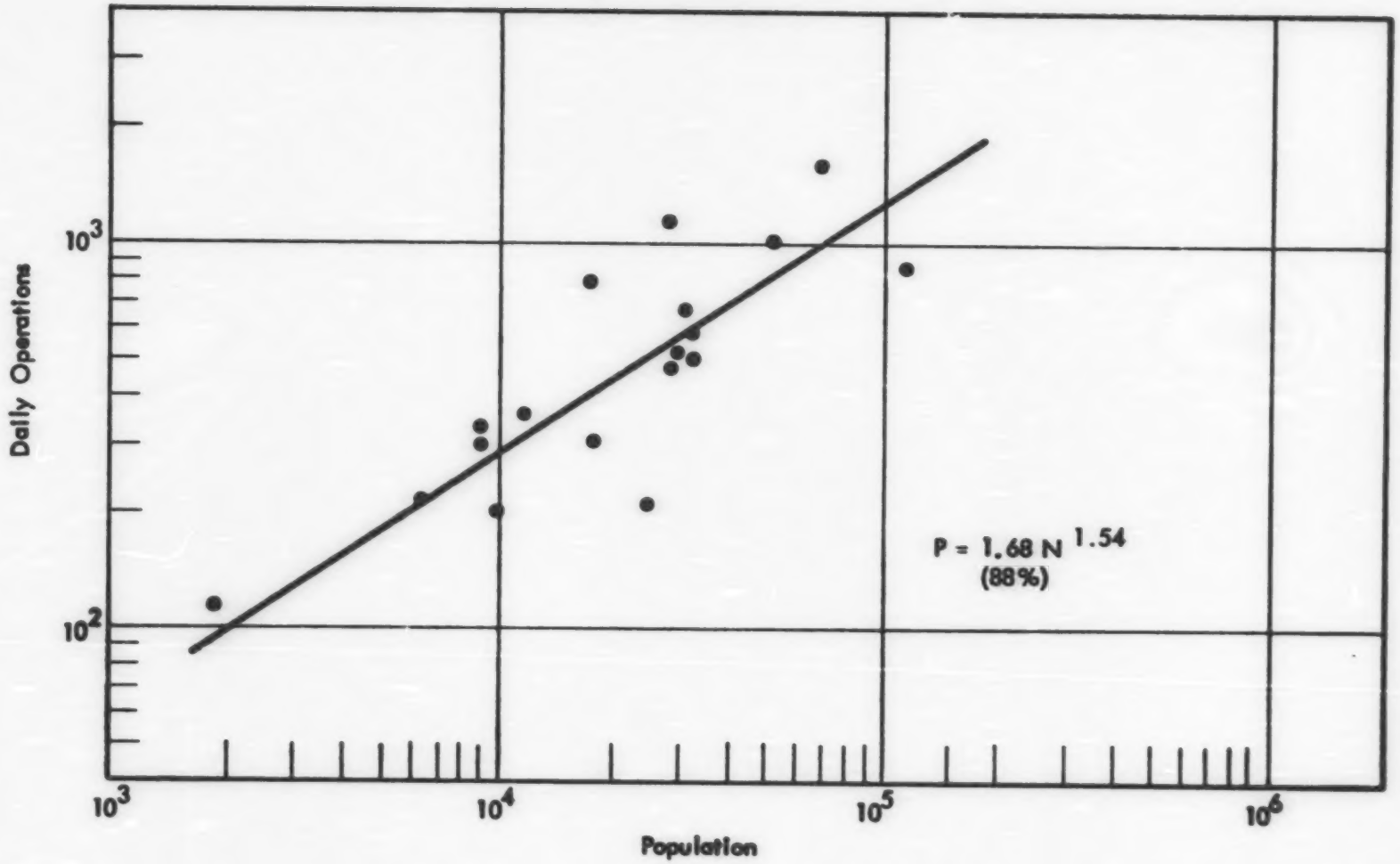

FIGURE 2. 23 AIRPORTS - 1972 BASELINE POPULATION WITHIN NEF 40

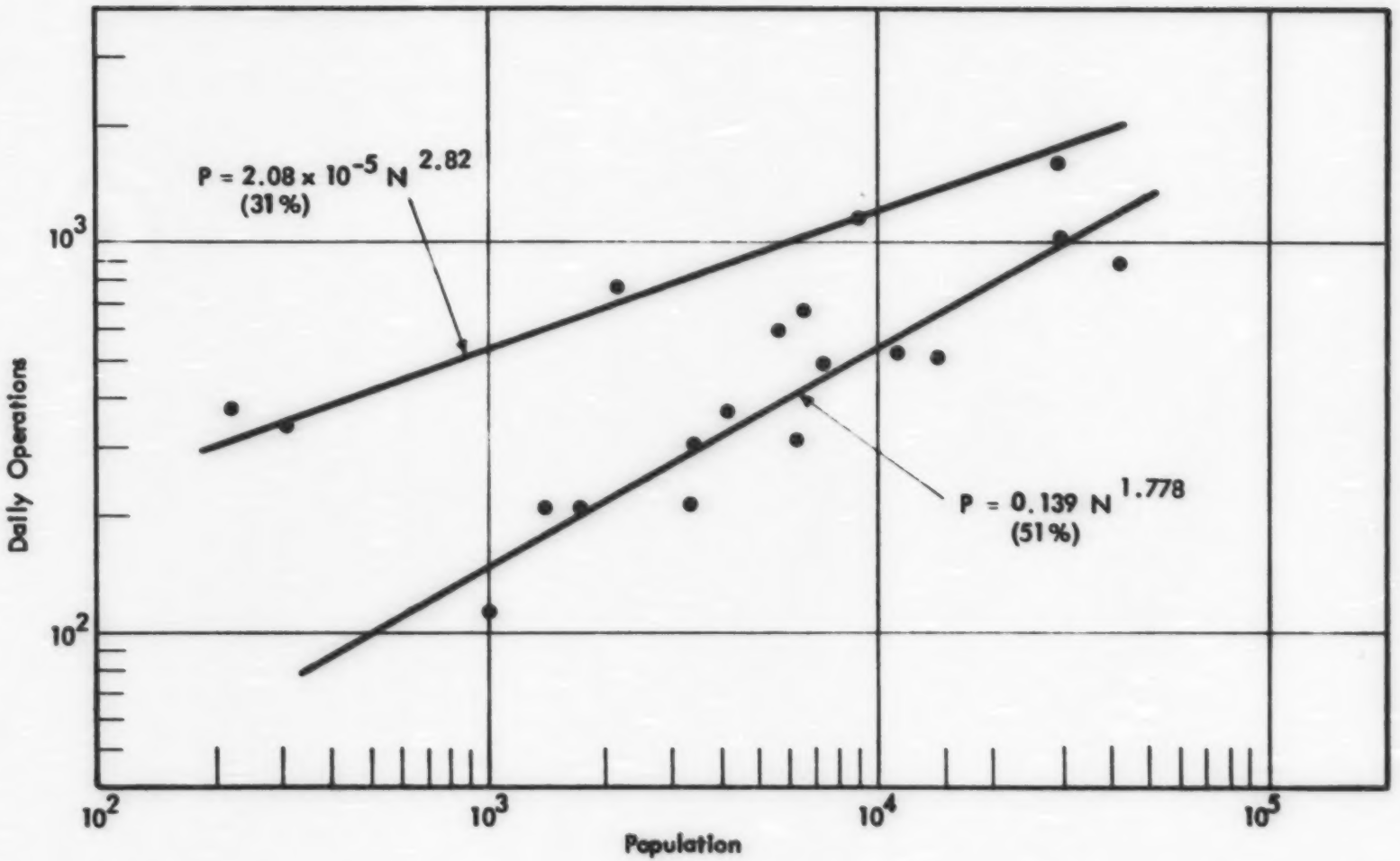

FIGURE 3. 23 AIRPORTS - 1972 BASELINE POPULATION WITHIN 45 NEF

This allows a several term model to be developed, with a weighting function applicable to each term to represent the proportion of total system operations represented by each term. Where the separate terms are linear, they are then combined into a single term expression.

On the basis of these considerations the following expressions were derived:

$$\text{NEF 30:} \quad P = 333\,N \tag{1}$$

$$\text{NEF 40:} \quad P = 1.48\,N^{1.54} \tag{2}$$

$$\text{NEF 45:} \quad P = 0.071\,N^{1.778} + 6.45 \times 10^{-6}\,N^{2.82} \tag{3}$$

where P is number of residents and N is total daily operations.

The operations at the 23 airports in 1972 represented 53% of the total daily operations of the air-carrier fleet. In order to make a national estimate the remaining operations need to be considered. For NEF 30 one needs only insert total operations into expression (1) since it is linear. In the NEF 40 and 45 cases, however, operations by airport size need to be computed due to the nonlinearity of the expressions. In Ref. 9 it is shown that airports having less than 20 operations (10 takeoffs plus 10 landings) contribute negligibly to the national areas of noise exposure. Using a similar approach, one can categorize airports by number of operations and derive estimates of populations exposed at the 173 airports (having 20 or more carrier operations daily) not included in the 23 airport study that are listed in the FAA Statistical Summary for 1972[11].

The computations for the populations exposed to NEF 40 and 45 at airports having 20 or more operations per day are summarized in Table I. Note that 13 of the 16 largest airports are already accounted for in the 23 airport study. Note also that the geometric mean of numbers of operations has been used to describe each grouping of operations.

The results of the above analyses are plotted in Figure 4 as a function of NEF as an aid in deriving a simple expression for estimating the national population exposed at any value of NEF between 30 and 45. Data from the 23 airport study on total population exposed, total land area, and impacted land area are also plotted on Figure 4, as well as the population exposed estimate from the EPA levels document. Note that the 23 airport study covers approximately 63% of the estimated national population exposed to significant aircraft noise. The estimate of 1972 total population exposed, P, to various NEF values can be expressed for the 23 Airport Study estimate by the following equation:

$$P = 10^{\frac{99-NEF}{10}} \qquad (4)$$

or, expressed in Day/Night Average Sound Level,

$$P = 10^{\frac{134-Ldn}{10}} \qquad (5)$$

The population exposure estimates in the "Levels" document do not lead to as simple an analytical expression, but can readily be used in impact analysis by interpolating noise exposure increments from the curvilinear function plotted on Figure 4. Because this earlier estimate of population exposed

TABLE I

ESTIMATE OF 1972 NATIONAL POPULATION
EXPOSED TO NEF 40 and 45

Annual Opns (1000's)	Total Airports	Within 23 A/P Study	Net	Pop.in NEF 40 (1000's)	Pop.in NEF 45 (1000's)
7-50	148	1	147	92	12
51-100	22	5	17	84	15
101-150	10	4	6	70	6
151-200	6	4	2	40	15
201-250	3	3			
251-300	2	2			
301-350	2	1	1	47	12
351-400	1	1			
401-450	1	1			
451-500	0	0			
501-550	0	0			
551-600	1	1			
Totals		23		523	176
	196			856	236

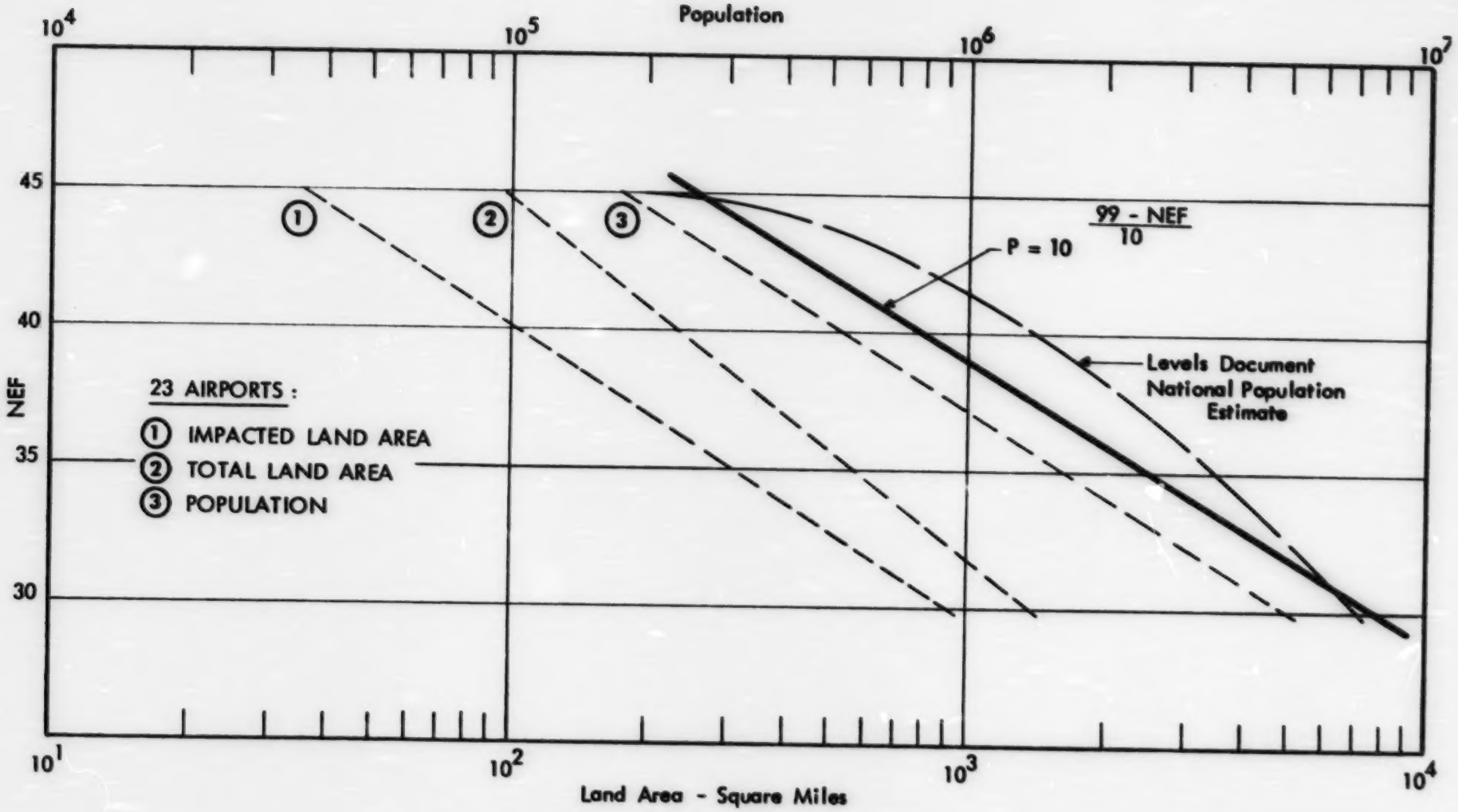

FIGURE 4. 1972 BASELINE LAND AREAS AND POPULATION EXPOSED AT DIFFERENT VALUES OF NEF

to aircraft noise is in the openly available literature, computations of impact for the various transport aircraft noise control measures are reported for both the new population function derived here from the 23 airport study and the previous function used in the "Levels" document. Note that the differences in estimated population impacted result only from the differences in the population distribution functions, since the change in noise exposure itself is the same in both calculations.

We start first with the new population distribution function. Performing the fractional impact analysis with the relationship expressed in equation (4) defines the baseline for 1972 as an equivalent of 5.33 million at a 100% impact level. The effects of the various regulatory actions can now be expressed in percentages of 1972 impact by determining the change in various NEF values brought about by the regulations. The numerical value, ten, of the denominator in the exponent of equations (4) and (5) permits a particularly simple expression to be derived for percentage of 1972 baseline impact in terms of the incremental change in NEF or average (equivalent) sound level resulting from a noise control mechanism:

$$\% \text{ of 1972 impact} = 10^{\frac{20+\Delta}{10}} \qquad (6)$$

where Δ is the weighted change in NEF (logarithmically averaged over the 30 to 45 NEF range).

In order to apply this relationship the effect of the regulations on future NEF values must be developed. The 23 airport study allows direct evaluation of the change in NEF values caused by normal changes in fleet composition, 3,000 foot-6°/3° intercept

and approach, and nacelle retrofit with sound absorptive materials (SAM) in conjunction with 6°/3° approaches. The separable effects of improved takeoff procedures, SAM alone, and 3,000 foot vectoring altitudes alone must be interpolated from the 23 airport study with assistance from other data. It should also be noted that the individual regulations could have greater or lesser effect on different aircraft and for different population groups around airports, depending upon whether the impacted population is exposed to predominantly approach noise or takeoff noise. In this analysis we are only examining a national average effect, using a composite aircraft fleet.

The primary results of the 23 airport study are contained in Figure 3.2-4 of Reference 8. This figure presents the aggregated percent change in impacted population at NEF 30 and 40 for the 23 airports, as a function of time, for the different actions considered, relative to the 1972 baseline. This figure indicates that the maximum effect will be reached in 1978, with little change in the next ten years. The change in impact can be derived by weighting the effect at NEF 40 by 0.1 and the effect at NEF 30 by 0.9. The resulting weighted change, through equation (6), provides a measure of the improvement expected.

In order to observe the effects of each regulation, account must be taken of the change in fleet composition between 1972 and 1978 due to retirement of older aircraft, growth, and the entrance of new aircraft complying with FAR Part 36. This can be calculated in terms of the change of equivalent noise levels for the 1978 fleet relative to the 1972 fleet. Using the data provided in the 23 airport study, this change is -1.0 dB. An alternate fleet projection in Reference 9 indicated a change

Of -0.8 dB. The value used here is from the 23 airport study. All results provided below are expressed in terms of percent of the two possible reference years, 1972 and 1978.

The changes in total impact derived on the basis of the above assumptions are listed in Table II for the 23 airport population distribution model. Results of a comparable computation using the "Levels" document population distribution function are listed in Table III. Comparison of the two tables indicates almost identical results, with average differences of one percent between the calculations using the two different population distribution functions.

TABLE II

PERCENT OF IMPACT PRODUCED BETWEEN DAY/NIGHT AVERAGE SOUND LEVELS OF 65 TO 80 DECIBELS BY VARIOUS REGULATORY ACTIONS - 23 AIRPORT POPULATION MODEL

Regulatory Combination	Δ -dB	Percent of Baseline Impact	
		Relative to 1972 Base	Relative to 1978 Base
1) No regulation	(-1.0)	79	100
2) Minimum altitude	(-1.3)	74	93
3) 6°/3° approach	(-1.8)	66	83
4) Takeoff procedures	(-1.6)	69	87
5) 2 + 3	(-2.1)	62	78
6) 2 + 3 + 4	(-2.7)	54	68
7) SAM	(-2.5)	56	71
8) SAM + 5	(-3.6)	44	55
9) SAM + 6	(-4.2)	38	48

TABLE III

PERCENT OF IMPACT PRODUCED BETWEEN DAY/NIGHT AVERAGE SOUND LEVELS OF 65 TO 80 DECIBELS BY VARIOUS REGULATORY ACTIONS - LEVELS DOCUMENT POPULATION MODEL

Regulatory Combination	Δ -dB	Percent of Baseline Impact Relative to 1972 Base	Percent of Baseline Impact Relative to 1978 Base
1) No regulation	(-1.0)	82	100
2) Minimum altitude	(-1.3)	75	94
3) 6°/3° approach	(-1.8)	68	84
4) Takeoff procedures	(-1.6)	71	88
5) 2 + 3	(-2.1)	64	80
6) 2 + 3 + 4	(-2.7)	57	69
7) SAM	(-2.5)	55	67
8) SAM + 5	(-3.6)	45	54
9) SAM + 6	(-4.2)	41	49

3. ANALYSIS OF THE IMPACT OF A NOISE CERTIFICATION RULE FOR PROPELLER DRIVEN SMALL AIRPLANES

The EPA proposal for small airplane noise certification[1] calls for a combination of noise limits for new type certificates and a reduction in noise levels for new production of older type-certificated aircraft, with various times of implementation. In order to examine the impact of the regulation one needs to consider various points in time, up until at least the year 1985. Unfortunately, no federal government studies of the nature of the DOT 23 airport study exist for small propeller driven aircraft. As a result, we need not only a noise model for the airport noise environment caused exclusively by small propeller aircraft, but also a model of the fleet growth and its change in noise characteristics with time.

We have available to us only a few airport noise analyses where only propeller driven aircraft are involved (because they probably do not constitute a major noise problem on a national basis). On the basis of these proprietary studies, and one publicly available[12], we have been able to develop a model to relate noise exposed areas to numbers of daily operations and NEF values. The area surrounded by a specified NEF value was found to vary as the antilog of NEF divided by 8. The relationship between area, A, and number of daily operations, N, for NEF 25, was found to be:

$$A = 1.085 \times 10^{-4} N^{1.2818} \qquad (7)$$

where A is area in square miles. Combining these relationships provides a baseline model of area as a function of NEF:

$$A = 10^{\frac{(10 \log N - NEF - 5.92)}{8}} \qquad (8)$$

where A is area in square miles.

The area of the airport needs to be subtracted from this to obtain net area subject to impact if populated. A reasonable average airport area to be subtracted is 0.68 square mile.

In the course of evolving the above relationships it was also found that one "average fleet" business jet was comparable in noise impact to approximately 200 "average fleet" propeller aircraft, and that when business jets are one percent or more of total operations, the coefficient of variation of log A with NEF becomes 12 instead of 8. This compares to 15 with the air carrier airports.

Next, a model for growth of the propeller driven small aircraft fleet is required. An FAA estimate of the total fleet size up to 1985 is provided in the EPA project report. This forecast shows a compound growth at 4.4% per year for the total fleet, with twins growing at a compounded growth of 6% per year. These growth rates are consistent with the 18 year trend line reported in Reference 13. Data from Reference 13 can also be used to show that about 60% of production enters the domestic fleet. In 1972, the data from Reference 13 also show that about 6,000 aircraft were added to approximately 120,000, again supporting about a 5% growth per year. Since very few aircraft are totally destroyed per year, essentially all aircraft remain in the fleet indefinitely. (For example, two-thirds of the Beech Bonanza's built 25 years ago are still in the domestic fleet.) Using 1972 as a base, twins were 7.5% of total production.

These assumptions can now be used to generate the size of the fleet for various years up to 1985, the end of the FAA forecast.

The effect of the new regulation on the composition of the fleet needs to be estimated. In these estimates we assume that the relative proportions of different models in the fleet remain fixed, with annual production increasing at 4.4% for singles, and 6% for twins. The following additional assumptions were made for different years:

1975 - 1976

No effect other than growth

1977

Beech twins, Cessna 185, 206, 310, 337 and short stack twin Aero Commanders are lowered 3 dB. These constitute ∿ 7.5% of production in 1971-1973.

1980

The effect of new type certificates has not yet been felt, but larger numbers of aircraft meeting 1977 requirements have been accumulated.

1985

Beech, Cessna, and Piper retain 86% of total production. Cessna has one new single, at 10% of total production, at -5 dB compared to 1972, and one new twin, 1% of total production, at -3 dB compared to 1972. Beech and Piper each have one new single and one new twin with the same production ratios.

The combinations of assumptions listed above were used to calculate the changes in fleet average sound level relative to a 1974 base case assumption, with and without the effects of the regulation. These values are listed in Table IV.

TABLE IV

CHANGE, Δ, IN PROPELLER DRIVEN AIRCRAFT
FLEET AVERAGE SOUND LEVEL IN DECIBELS
RELATIVE TO 1974 FLEET AVERAGE SOUND LEVEL

Year	1977	1980	1985
Normal growth without regulation	0.37	0.87	1.88
Incremental change due to regulation	-0.01	-0.04	-0.12
Net change relative to 1974 base with regulation	0.36	0.83	1.76

Without a national model for population affected by small propeller driven aircraft noise exposure we must resort to an average population density analysis. Since the number of airports constructed per year is almost the same as the number taken out of service, we will assume that fleet growth must be absorbed by increasing operations at each airport. We will also assume that the types of aircraft using each airport are in proportion to their total number in the national fleet.

The model for airport area as a function of number of operations covers the range from 20 NEF to 35 NEF, or 55 L_{dn} to 70 L_{dn}. In actuality, no small aircraft airport, with no jet operations, has an NEF value as high as 30 NEF outside the airport boundary. Using an assumed airport area of 0.675 square miles, it requires in excess of 285 operations per day (104,000 annual) of the present fleet composition to move the 20 NEF boundary outside airport property. On the other hand, it is extremely unlikely for an airport to have more than 300,000 operations per year in 1975 and still not handle jet operations. In this analysis we consider the two extremes of 100,000 and 300,000 operations per year in 1975 as our base case.

One can apply the fractional impact analysis method to the propeller aircraft model without knowledge of actual population densities as long as it is assumed that population density is uniform with NEF or L_{dn} in the near vicinity of an airport. That is,

$$\frac{\Sigma(FI_i)x(P_i)}{P} = \frac{\Sigma(FI_i)xP_oA_i}{P_o\Sigma A_i} = \frac{\Sigma(FI_i)x(A_i)}{A} \qquad (9)$$

for uniform population density, P_o.

Performing the calculations with these assumptions leads to the results in Table V.

TABLE V

PERCENT OF POPULATION WHO HAVE AN EQUIVALENT 100% IMPACT FROM EXPOSURE TO PROPELLER DRIVEN SMALL AIRCRAFT NOISE AT DAY/NIGHT AVERAGE SOUND LEVELS OF 55 DECIBELS OR MORE

	100,000 Opns/Year			300,000 Opns/Year		
	1977	1980	1985	1977	1980	1985
Without regulation	4.8	5.9	7.6	9.9	10.3	11.7
With regulation	4.8	5.8	7.3	9.9	10.2	11.3
Percent reduction with regulation	0.3	1.1	3.4	0.3	1.1	3.4

The basic effect of the regulation would be to reduce noise impact by 1.1 percent in 1980, and 3.4 percent in 1985. The effect in later years would be more substantial as larger numbers of newer, quieter aircraft enter the total fleet.

4. ANALYSIS OF THE EFFECT OF LIMITED SST OPERATIONS AT SELECTED AIRPORTS

The EPA proposal for noise certification for supersonic transport aircraft[4] states, in essence, that the initial production run of Concorde aircraft should be allowed to operate as presently designed, but that future production aircraft be required to comply with the same noise regulation as subsonic transport aircraft. The purpose of the analysis described here is to assess the effective impact of limited operations of the initial production aircraft at certain specific airports. Two levels of activity are considered, four and eight operations per day (two each and four each takeoffs and landings per day). The airports considered are:

Boston Logan	(BOS)
Los Angeles International	(LAX)
Miami International	(MIA)
New York - Kennedy	(JFK)
San Francisco International	(SFO)
Seattle - Tacoma	(SEA)
Washington, D.C. - Dulles	(IAD)

All seven of these airports are analyzed, for conventional transport aircraft, in the DOT 23 airport study[8]. In this case we can derive individual fleet average noise levels for operations at each airport based on the 1972 fleet mix at the airport. Similarly, individual functions of population exposed to different NEF values can be derived for each airport.

Noise level equivalents for the Concorde were obtained for each airport by first deriving the equivalent fleet sound

levels at the three FAR 36 locations for the 1972 fleet mix at each airport. These levels are the values of sound level that, when added to ten times the logarithm of operations per day, will produce the same cumulative noise exposure as the original fleet mix. Concorde noise levels were then compared to the fleet average noise level at each airport and FAR 36 location to obtain the number of fleet average operations that were equivalent to one Concorde operation. The change in Day/Night Average Level at each airport was then computed by adding the Concorde operations to those of the 1972 base case at each airport. A net increase in decibels was obtained by averaging the increase in takeoff and sideline sound levels. The values obtained are listed in Table VI.

TABLE VI

INCREMENTAL INCREASE IN DAY/NIGHT AVERAGE SOUND LEVEL IN DECIBELS DUE TO SST OPERATIONS, RELATIVE TO 1972 BASE

Airport	4 opns/day	8 opns/day
Boston	0.31	0.60
Los Angeles	0.07	0.18
Miami	0.47	0.89
New York	0.19	0.38
San Francisco	0.26	0.50
Seattle	0.60	1.12
Washington, D.C.	1.02	1.85

Population distribution models for each airport were derived from the population data of Ref. 8 for noise exposure between 30 and 45 NEF, or Day/Night Average Sound Levels of 65 to 80 decibels. It was found advantageous to approximate the population versus noise exposure function by two slopes, one for L_{dn} values of 65 to 75 decibels and one for 75 to 80 decibels. The functions have the generic form of equation 10:

$$K_1 \log P = K_2 - L_{dn} \qquad (10)$$

where P is number of people at a specified value of L_{dn}, and K_1, and K_2 are constants for the two equations used at each airport. The values obtained are listed in Table VII.

(Note that a national average slope was used for Dulles since a population value for only NEF 30 was available; there are no people reported as inside NEF 40 or 45 in Ref. 8.)

TABLE VII

COEFFICIENTS FOR COMPUTING POPULATION EXPOSED TO VARIOUS DAY/NIGHT AVERAGE SOUND LEVEL AT SEVEN AIRPORTS - 1972 BASE

Airport	$65 \leq L_{dn} \leq 75$		$75 \quad L_{dn} \leq 80$	
	K_1	K_2	K_1	K_2
Boston	8.834	114.770	6.605	104.756
Los Angeles	13.175	137.077	19.763	167.860
Miami	10.616	122.485	7.496	108.530
New York	15.242	151.954	11.737	134.260
San Francisco	9.634	114.085	7.194	104.186
Seattle	11.724	124.690	7.072	104.971
Washington, D.C.	10	100.44	10	100.44

The data of Table VI were then combined with the equations of population exposed to various noise levels to compute the change in impact that would be expected by the SST operations at each airport. These computations are summarized in Table VIII where the equivalent one-hundred percent impacted population and the percent change in impact relative to the 1972 base case are provided.

TABLE VIII

EQUIVALENT IMPACTED POPULATION (P_{eq}) AND THE CHANGE IN POPULATION IMPACTED BY ADDING SST OPERATIONS - DAY/NIGHT AVERAGE SOUND LEVELS BETWEEN 65 AND 80 DECIBELS - 1972 BASE YEAR

Airport	Base Case P_{eq}	4 SST per day P_{eq}	% of Base	8 SST per day P_{eq}	% of Base
Boston	3.03×10^5	3.30×10^5	108.9	3.57×10^5	117.8
Los Angeles	1.64×10^5	1.66×10^5	101.2	1.69×10^5	104.3
Miami	1.81×10^5	2.01×10^5	111.0	2.23×10^5	115.5
New York	3.54×10^5	3.65×10^5	103.1	3.77×10^5	106.5
San Francisco	1.23×10^5	1.33×10^5	108.1	1.42×10^5	115.5
Seattle	8.28×10^4	9.42×10^4	113.8	1.05×10^5	127.3
Washington, D.C.	2.38×10^3	3.01×10^3	108.9	3.57×10^3	153.1

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APPENDIX 1

THE METHODOLOGY OF FRACTIONAL IMPACT ANALYSIS OF ENVIRONMENTAL NOISE

1. Discussion

The underlying concept for noise impact assessment in this analysis is to express the change in human response expected from the people exposed to the environmental noise exposure being considered. Three steps are involved: a) definition of initial acoustical environment; b) definition of final acoustical environment; c) definition of the relationship between the specified noise environment and the degree of its "impact" in terms of its expected human response.

The first two components of the assessment are entirely site or system specific, relating to either estimates or measurement of the environmental noise before and after the action being considered. The same approach is used, conceptually, whether one is examining one single house near one proposed road, the entire highway system, or the totality of the nation's airports. The methodology for estimating the noise environment will vary widely with the scope and type of problem, but the concept remains the same.

In contrast to the widely varying possible methodologies for estimating the noise environment in each case, the relationships to human response can be quantified by a single methodology for each site or noise producing system considered in terms of the number of people in occupied places exposed to noise of a specified magnitude. This is not to say that individuals exhibit the same susceptibility to noise; they do not. Even

groups of people may vary in response depending on previous exposure, age, socioeconomic status, political cohesiveness and other social variables. In the aggregate, however, for residential locations the *average* response of groups of people is quite stably related to cumulative noise exposure as expressed in a measure such as the average yearly L_{dn}. The response we use is the *general adverse reaction* of people to noise. This response is a combination of such factors as speech interference, sleep interference, desire for a tranquil environment, and the ability to use telephones, radio, TV satisfactorily. The measure of this response is related to the percentage of people in a population that would be expected to indicate a high annoyance to living in a noise environment of a specified level of exposure.

A generalized expression for the percentage of a population expected to be highly annoyed (i.e. %HA) when exposed to a specified environmental noise level is:

$$\% \text{ HA} = 2(L_{dn}-50)$$

Note that the data from which this expression was derived also show that, even for situations where, say, 20% of the people would be expected to be highly annoyed by their noise environment, the majority of the population is not at all annoyed.

The above considerations allow us to specify, for a variety of spaces or land uses, numerical values for noise levels which, if not exceeded, would provide entirely acceptable acoustical environments. That is, if these values were not exceeded, we would expect no impact from environmental noise.

2. Quantifying Noise Impact

EPA in Reference 7 has specified an L_{dn} value of 55 as the general level of outdoor environmental noise in residential areas that is "requisite to protect public health and welfare with an adequate margin of safety." One can specify that, in a noise impact analysis levels below this value will have zero impact, while some degree of impact will exist if this value is exceeded. The range of equivalent noise level between totally acceptable and totally unacceptable conditions is approximately 20 decibels, that is, L_{dn} values between 55-60 and 75-80.

The percent of noise impact at a residential location can thus be defined as ranging from zero, if the exposure is less than L_{dn} of 55, to 100% when the local noise level exceeds these criterion levels by 20 decibels. We can express, for every location, the fraction of 100% noise impact that the local exceedance of the criterion level implies. Mathematically this Fractional Impact (FI) is defined as:

$$FI = 0.05\ (L_{dn}-55) \quad \text{for } L_{dn} > 55$$

$$FI = 0 \quad \text{for } L_{dn} \leq 55$$

Note that FI can exceed unity, if L_{dn} exceeds 55 by more than 20 dB.

3. Calculation of Total Impact

In order to introduce the number of people affected by each level of environmental noise into the analysis, it is assumed that a trade-off can be made between the *intensity* and the *extensity* of noise impacts; that is, it is assumed that a

moderate exceedance of criterion levels for a large group of people would be expected to be of greater impact than a large exceedance of criterion levels for a small number of people. A way of defining the impact is to determine the fractional parts, P_i, of the total population being considered, P, who have various exceedances, $Ldn_i - 55$. Thus the Equivalent Noise Impact (ENI) of a specific noise environment for a population P can be expressed as:

$$ENI = \Sigma\ FI_i\ P_i$$

This descriptor (ENI) might be considered as the "equivalent population" 100% impacted by noise. It provides an estimate as to the magnitude of the impact.

The impact of a change in noise environment due to regulatory action can be expressed either as a change in ENI before and after regulation, or on the more easily understood basis of percent change in impact. The "before regulation" noise environment can be defined as 100 percent of existing impact, and the "after regulation" impact can then be expressed as that percent of the original impact remaining. Mathematically this expression is:

$$\frac{ENI_A}{ENI_B} \times 100$$

where the subscripts A and B refer to the values of ENI after and before regulation. To be meaningful these values need to be computed using the same total population. Ideally, the total national population affected by the noise in question should be used for the population base.